THE BAKERIAN LECTURE.—"On the Corona of the Sun." By WILLIAM HUGGINS, D.C.L., LL.D., F.R.S. Received June 11, 1885. Read June 11, 1885.

Περὶ δὲ τον χρόνον, ὅν ἐν τῇ Ἑλλάδι ἐνεσπούδαζεν, ἐπεῖχε τὸν οὐρανον διοσημία τοιαὐτη, τὸν τοῦ Ἡλίου κύκλον περιελθῶν στέφαρος, ἐοικὼς Ἴριδι, τὴν ἀκτῖνα ἠμαυροῦ.

Philostratus, "Life of Apollonius," bk. viii, ch. xxiii (ed. Leipzic, 1709).

Ἀλλὰ περιφαίνεταί τις αὐγὴ περὶ τὴν ἴτυν, αὐκ ἐῶσα βαθεῖαν γίνεσθαι τὴν σκιὰν καὶ ἄκρατον.

"Plut. Opera Mor. et Phil.," vol. ix, p. 682 (ed. Leipzic, 1778).

The sun is the only star the corona of which we have been able to observe, for all other stars are too distant to give true images in the telescope. If the sun were removed to a distance equal to that of the nearest star, its disk would subtend less than the one-hundredth of a second of arc. We have also to consider the small relative brightness of the corona, the light from which has been estimated at different times to be from $\frac{1}{100000}$ to about the $\frac{1}{400000}$ part of the sun's light. It is, indeed, possible that stars which have a higher temperature than our sun, are surrounded by coronæ of greater extent and brightness.

At the eclipse of 1882, some information was obtained of the sun's condition in relation to that of the brighter stars. The photographs of the more refrangible part of the spectra of stars, which I had the honour to lay before this Society in 1879,* gave a clue by which the stars could be arranged in a serial order, at the head of which stand the bright stars Vega and Sirius. I ventured to suggest that the differences in their spectra might be due primarily to temperature; and even to make the further suggestion, that the hotter stars were probably the younger stars, and that we had obtained possibly some indications of the relative ages of the stars. The position of the sun came some distance down in the series, very near the position of Capella, and just above the stars which begin to show a yellow tinge in their light. In the ordinary solar spectrum it is difficult to distinguish the ultra-violet group of hydrogen lines, upon the character of which this serial arrangement was mainly based, but in the photograph of the spectrum of the corona obtained during the Egyptian eclipse, Captain Abney and Professor Schuster have been able to recognise very thin bright lines corresponding to the lines of this group.† These lines were not due to the corona, but to

* "Proc. Roy. Soc.," vol. 30, p. 20; also "Phil. Trans.," vol. 171, p. 669.

† "Phil. Trans.," 1883, p. 267.

prominences at the base of the corona. The thin condition of these lines, as well as the breadth of the lines of calcium at H and K, confirms the position which I had ventured to give to the sun relatively to some of the brighter stars, namely as belonging to the least fervid of the white stars, and just above those which begin to show a yellow light.

There are indeed some stars in the spectra of which the line D_3 which is seen in the prominences, and in the lower parts of the corona of the sun, appears as a bright line, but this may be due to gas below any true corona, which may be about these stars.

There are also the so-called nebulous stars, which are surrounded by an aureole of faint light of measurable angular extent, but it would seem more probable that these belong to, and should be discussed with, the clusters and nebulæ, and should not be regarded as exhibiting a corona of the nature of that which surrounds the sun.

So far then as our present powers of observation go, the corona of the sun stands alone; it is therefore the more to be regretted that the observations of this object are beset with great and peculiar difficulties. The absorption and scattering of the sun's light by our atmosphere, amounting according to Professor Langley to nearly 40 per cent.,* which are essential to the maintenance of the conditions under which life, as it now exists, is possible upon the earth, comes in, in this case, so seriously to our disadvantage that the corona can be seen for a few minutes only at long intervals. It is only on the rare occasions when the moon coming between us and the sun cuts off the sun's light from the air at the place where the eclipse is total, that we can see the corona through the cone of unilluminated air which is in shadow. On an average once in two years, for from three to six minutes, the corona is visible, and then only over a very narrow strip of the earth's surface. It is not surprising that many attempts have been made to observe the corona without an eclipse. The earlier attempts were based upon the hope that if the eye were protected from the intense direct light of the sun, and from all light other than that from the sky immediately about the sun, the eye might become sufficiently sensitive to perceive the corona. In the later attempts, success has been sought for from the great diminution of air-glare which takes place at high elevations, when the denser and more dusty parts of the atmosphere are left below the observer. Professor Langley made observations on Mount Etna, and also on Mount Whitney, 15,000 feet high. He says:—"I have tried visual methods under the most favourable circumstances, but with entire non-success." Dr. Copeland, assistant to Lord Crawford, observed at Puno at a height of 12,040 feet. In his report he says:† —"It ought to be mentioned that the appearances produced by the illuminated atmosphere were often of the most tantalising description,

* "Amer. J. of Science," September, 1884.

† Copernicus, vol. iii, p. 212.

giving again and again the impression that my efforts were about to be crowned with success."

The spectroscopic method by which the prominences may be seen without an eclipse, fails for the corona, because a small part only of the coronal light is resolved by the prism into bright lines, and of these lines no one is sufficiently bright and coextensive with the corona to enable us to see the corona by its light.

Let us look at some of the conditions of the problem. As the obstacle to our seeing the corona consists of the bright screen of illuminated air which comes in before it, it is of importance to consider the relative degree of brightness of the air-glare, under favourable conditions, to that of the corona behind it.

During the eclipse of 1878, Professor J. W. Langley found the apparent brightness of the coronal light at 1′ from the limb of the moon to be six times greater than that of the full moon, but at 3′ distance, the light to have fallen off to one-tenth of the light of the full moon.* Professor Harkness concludes for the same eclipse:—(1.) The total light of the corona was 3·8 times that of the full moon, or 0·0000069 of that of the sun. (2.) The coronal light varied inversely as the square of the distance from the sun's limb. (3.) The brightest part of the corona was 15 times brighter than the surface of the full moon. (4.) The corona of December 12, 1870, seems to have been $7\frac{1}{4}$ times brighter than that of July 29, 1878.† In his report on the eclipse of 1883, M. Janssen says:—"Cette expérience a montré qu'à Caroline l'illumination donnée a été plus grande que celle de la pleine lune."‡

The chief point of importance for this inquiry lies not so much in the actual value of the coronal light as in the relation of that value to the brightness of the illuminated air near the sun. Many observers have borne testimony to the continued visibility of the corona for some minutes (from three minutes to twelve minutes) after the end of totality.

The observations which give to us direct information on this point are those which have been made of the planets Venus and Mercury when they come in between us and the sun. It is obvious that as the planet approaches the sun it comes in before the corona and shuts off the light which comes from it. Under these circumstances the observer sees the sky in front of the planet to be darker than the adjoining parts, that is to say, the withdrawal of the coronal light from behind has made a sensible diminution of the brightness of the sky. It follows that the part of the sky about the sun, behind which the corona is situated, and to which its light is added, is brighter than

* Washington Observations. Reports of Solar Eclipses, 1878 and 1880, p. 214.

† Ditto, p. 392.

‡ "Annuaire pour l'An 1884" (B. des Longitudes), p. 875.

the adjoining parts, in a degree not far removed from the eye's power of distinguishing adjacent areas which differ by a small degree of brightness.

If, therefore, by any method of observation even a small advantage could be given to the coronal light as compared with the air-glare, and, especially, if, at the same time, we could by any method accentuate the small difference of illumination, a method might be found by which the corona could be observed.

When the report of the photographs taken during the Egyptian eclipse of 1882 reached this country, I was led to conclude that the coronal light as seen from the earth was strong in the violet, and probably to some extent also in the ultra-violet part of the spectrum.

Apart from the question of the greater relative intrinsic intensity of the more refrangible region of the coronal light as a whole, or of any one of its components (its gaseous component gave bright lines in the violet region), there are two considerations which show us that the coronal light should be strong in the violet as compared with the air-glare near the sun.

The selective absorption of our atmosphere would cause the light scattered by it in the near neighbourhood of the sun to be relatively poor in this part of the spectrum; but there is a second cause acting in the same direction, which arises from the selective power of absorption of the sun's atmosphere.

The absorption which the photospheric light suffers from the solar atmosphere has been investigated by Professor Langley, Professor Pickering, and especially with great minuteness by Professor H. C. Vogel. Vogel found that while at the edge of the sun's disk the red light was reduced to 30 per cent. of its value at the centre of the disk, the violet light was reduced to 13 per cent.

Vogel sums up by saying that if the solar atmosphere were removed, the brightness of the violet part of the sun's light would be increased about three times, but the red light one and a-half times only.* The selective action would doubtless be more strongly marked beyond the visible limit.

The rapid increase of absorption near the sun's limb, in Vogel's observations, indicates a low and dense solar atmosphere. Professor Langley agrees in this view of the sun's atmosphere. He says, "The portion of the (sun's) atmosphere chiefly concerned in absorption, I have been led to believe, from several considerations, is extremely thin, and I am inclined to think is mainly identical with the reversing layer at the base of the chromosphere."

Professor Hastings also considers the "layer which produces absorp-

* "Spectralphotometrische Untersuchungen." "Monatsbericht der K. Ak. d. Weissenschaften." Berlin, März, 1877. Also "Ueber die Absorption der chemicale wirksamen Strahlen in der Atmosphäre der Sonne," *ibid.*, Juli, 1872.

tion to be very thin," but he prefers to regard this layer as consisting not of gas, but of "a thin smoke-like envelope of precipitated material."* Professor Pickering assumes the existence of an absorbing atmosphere about equal in height to the sun's radius, but we shall see further on that there are reasons which make this supposition extremely improbable.

The light emitted by the corona, whether by the incandescent particles or by the gas mingled with them, which lies outside the low region of absorption, will not have been subjected to the same selective absorption as the photospheric light which is emitted below this region. For this reason the light emitted by the corona will be richer in the more refrangible rays than the sun's light before it enters our atmosphere, and will be in a still larger degree richer in these rays than the solar light which has been scattered by our atmosphere near the sun. These considerations led me to hope that if the corona were observed by this kind of light alone it would be at some advantage relatively to the air-glare which comes in before it. It was of importance at the same time to magnify the small advantage the coronal light might have by some method of observation which could bring out strongly minute differences of illumination. Such a power is possessed by a photographic surface. I took some pains to satisfy myself "that under suitable conditions of exposure and development a photographic plate can be made to record (strongly) minute differences of illumination existing in different parts of a bright object, such as a sheet of drawing paper, which are so subtile as to be at the very limit of the power of recognition of a trained eye, and as it appeared to me, those which surpass that limit."†

* "Constitution of the Sun," "Amer. J. of Science," vol. xxi, p. 33.

† "Proc. Roy. Soc.," 1882, p. 411.

Professor Stokes has suggested the following method of increasing the intensity of that part of the coronal light which is polarised relatively to the glare from the sky. He says in a letter, which he permits me to add here:—"The light of the corona is known to be strongly polarised, while the atmospheric glare would show no sensible polarisation. Let p be the intensity of the coronal light along any radius vector which is polarised radially, and q the intensity polarised tangentially, and let $2a$ be the intensity of the glare. Then, without polarising the light, the intensity of the coronal light relatively to the glare would be as $p+q$ to $2a$. Suppose now the light falling on the plate to be polarised, say, in a north and south plane. Then north and south the ratio of the coronal light to that of the glare would be increased to p to a, while in east and west directions it would be reduced to q to a. In north-east and south-west as well as in north-west and south-east directions, the ratio would be the same as without polarisation. If in four successive photographs the plane of polarisation were set to north, north-east, east, south-east, we should get a relative increase in coronal light, in one or other of the photographs, all round the sun. It would be least in north-north-east, east-north-east, &c., directions, where it would be $p\cos^2 22\frac{1}{2}^\circ + q\sin^2 22\frac{1}{2}^\circ$ to a, or about $0{\cdot}85p + 0{\cdot}15q$ to a.

"The most convenient way of polarising would probably be to use a Nicol of some size not far from the plate."

In my early experiments I made use of coloured glass, or a cell containing a coloured liquid, for the purpose of isolating the violet part of the spectrum,* but afterwards I obtained the desired light-selection in the film itself by the use of argentic chloride, which Captain Abney had shown to be most strongly sensitive to light from *h* to a little beyond H.† Plates prepared with argentic chloride possess a further advantage for this work in consequence of the greater steepness of their gradations of density corresponding to differences of light-action as compared with argentic bromide plates.

When very small differences of illumination only, existing close about a body so enormously bright as the sun, have to be photographed, the most minute precautions have to be taken to avoid false effects upon the plate, which may arise from several causes. Lenses should not be used to form the sun's image on the sensitive surface, in consequence of possible false light about the image which may come from outstanding aberrations, though they have been corrected for photographic work, and from reflections at the surfaces of the lenses. I therefore employed a mirror of speculum metal. Other necessary precautions are described in my paper, namely, the position of the shutter very near the focal plane; protecting the sensitive surface from the sun's direct light by a metal disk a little larger than the sun's image; placing before the apparatus a long tube fitted with diaphragms to prevent light from the sky, excepting near the sun, from entering the apparatus; backing the plates with asphaltum varnish; and some others.‡

In my experiments in 1882 I used a Newtonian telescope by Short, but afterwards a fine mirror made by the late Mr. Lassell, which was so arranged that the image was formed directly upon the plate without reflection from a second mirror.§

About twenty plates were taken in 1882, in all of which an appearance more or less coronal in character is to be seen about the sun's image. After a very critical examination of these plates, in which I was greatly helped by the kind assistance of Professor Stokes and of Captain Abney, there seemed to be good ground to hope that the

* "Proc. Roy. Soc.," vol. xxxiv, pp. 411, 412.

† "Proc. Roy. Soc." vol. xxxiii, p. 175.

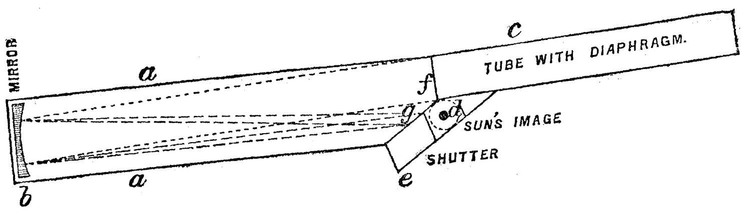
‡ "Proc. Roy. Soc.," vol. xxxiv, p. 409, also Report Brit. Ass., 1883, p. 348. See also the photographic experiments of Dr. Lohse, "Vierteljarsschrift Ast. Gesell.," Bd. xv, S. 134. Dr. Lohse sums up an account of his methods and results thus:—"Es gelang aber dieselben (die Schwierigkeiten) zu überwinden und Resultate zu erhalten welche zu einer Fortsetzung der—hier freilich selten möglichen und mit grösserem Vortheil in möglichst hoher Lage anzustellenden—Experimenten ermuthigen."

§ "I am indebted to Miss Lassell for the loan of a 7-foot Newtonian telescope made by the late Mr. Lassell. The speculum, which is 7 inches in diameter, possesses great perfection of figure, and still retains its original fine polish. I decided not to

corona had really been obtained upon the plates. On one plate especially forms resembling closely in character those present in the photographs of the eclipse of that year were visible.

In the following year, 1883, working with the Lassell mirror, I found that when the sky was free from clouds, but whity from a strong scattering of the sun's light, the sun's image in the photographs was well defined upon a sensibly uniform surrounding of air-glare, but without any such sudden increase of illumination near the sun's limb, or other indication which might be due to the corona. It was only when the sky was exceptionally clear that coronal appearances presented themselves with more or less distinctness.

use more than 3½ inches of the central portion of the speculum, partly for the reason that a larger amount of light would be difficult of management, and partly because this restriction of the aperture would enable me to adopt the arrangement which is shown in the diagram.



"It will be seen at once from an inspection of the diagram that in this arrangement the disadvantage of a second reflection by the small mirror is avoided, as is also the mechanical inconvenience of tilting the speculum within the tube as in the ordinary form of the Herschelian telescope. The speculum *b* remains in its place at the end of the tube *a*, *d*. The small plane speculum and the arm carrying it were removed. The open end of the tube is fitted with a mahogany cover. In this cover at one side is a circular hole, *f*, 3¼ inches in diameter, for the light to enter; below is a similar hole, over which is fitted a framework to receive the 'backs' containing the photographic plates, and also to receive a frame with fine ground glass, for putting the apparatus into position. Immediately below, towards the speculum, is fixed a shutter, with an opening of adjustable width, which can be made to pass across more or less rapidly by the use of india-rubber bands of different degrees of strength. In front of the opening *f* is fixed a tube, *c*, 6 feet long, fitted with diaphragms, to restrict as far as possible the light which enters the telescope to that which comes from the sun and the sky immediately around it. The telescope-tube, *a a*, is also fitted with diaphragms, which are not shown in the diagram, to keep from the plate all light except that coming directly from the speculum. It is obvious that, when the sun's light entering the tube at *f* falls upon the central part of the speculum, the image of the sun will be formed in the middle of the second opening at *d*, about 2 inches from the position it would take if the tube were directed axially to the sun. The exquisite definition of the photographic images of the sun shows, as was to be expected, that this small deviation from the axial direction, 2 inches in 7 feet, does not affect sensibly the performance of the mirror. The whole apparatus is firmly strapped on to the refractor of the equatorial, and carried with it by the clock motion."—Report B. Ass. Advanc. Science, 1883 p. 346.

The total solar eclipse of May 6, 1883, furnished an opportunity of comparing the photographs taken with an eclipsed sun with those taken in this country without an eclipse. On the day of the eclipse the weather was bad here, but plates taken before and after the eclipse were placed in the hands of Mr. Wesley, who had had much experience in making drawings from photographs taken during former eclipses. Mr. Wesley drew from these plates before any information reached this country of the results obtained at Caroline Island; he was, therefore, wholly without bias in the drawings which he made from them. When these drawings were compared afterwards with the Caroline Island plates, the general resemblance of the corona was strong, and the identity of the object photographed in England and at Caroline Island seemed placed beyond doubt by a remarkably formed rift on the east of the north pole of the sun, which is seen very nearly in the same position in the English plates and in those taken during the eclipse. This rift, slightly modified in form, was found to be present in a plate taken about a solar rotation-period before the eclipse, and also on a plate taken about the same time after the eclipse.*

In 1884, a grant from the fund placed annually by the Government at the disposal of the Royal Society was put into the hands of a committee appointed by the Council of the Royal Society for the purpose of photographing the corona at a place of considerable elevation. The Committee selected the Riffel, near Zermatt, which has an elevation of 8,500 feet, and appointed as photographer Mr. Ray Woods, who, as assistant to Professor Schuster, had photographed the corona during the eclipse of 1882, and who in conjunction with Mr. Lawrance had photographed the eclipse of the following year at Caroline Island.

Unfortunately during this year a very large amount of scattered light was always present about the sun, arising, it would seem, from

* Report B. Ass. Advanc. Science, 1883, p. 348, and Plates XI and XIa.

It seems desirable to put on record here a letter written by Mr. Lawrance to Professor Stokes, dated September 14, 1883:—"Dr. Huggins called upon Mr. Woods this morning and showed us the drawings Mr. Wesley has made of his coronas. He told us that he particularly did not wish to see our negatives, but that he would like us to compare his results with ours. We did so, and found that some of the strongly marked details could be made out on his drawings, a rift near the north pole being especially noticeable; this was in a photograph taken on April 3, in which the detail of the northern hemisphere is best shown, while the detail of our southern hemisphere most resembles the photograph taken on June 6; in fact, our negatives seem to hold an intermediate position. Afterwards I went with Dr. Huggins and Mr. Woods to Burlington House to see the negatives. The outline and distribution of light in the inner corona of April 3 is very similar to that on our plate which had the shortest exposure; the outer corona is, however, I think, hidden by atmospheric glare. As a result of the comparison I should say that Dr. Huggins' coronas are certainly genuine as far as 8′ from the limb."

finely-divided matter of some sort in the higher regions of the air. Mr. Woods observed from the Riffel that when no visible cloud or mist was present, there came into view a great aureole around the sun, about 44° in diameter, of a faint red colour at the outside and passing into bluish-white near the sun. This was clearly a diffraction phenomenon showing the presence of minute particles of matter of some sort in the higher regions of our atmosphere.

The abnormally large amount of air-glare from this cause—even on the finest days—prevented any success in photographing the corona in this country, and went far to counteract the advantages of being above the denser strata of air which Mr. Woods would have gained on the Riffel under ordinary circumstances.

Mr. Woods sums up his results in the following words:—"Results on the same day are almost, if not quite, alike both with the disk and without. The corona varies more or less from day to day. The clearer the day the better the results."*

During the last two years the sky in this country has been too bright from scattered light to make it possible to obtain successful photographs of the corona.†

We have now to discuss the probable nature of the corona.‡

The drawings, but especially the photographs, of the solar eclipses of the last twenty-five years show that notwithstanding great changes in form and in brightness, the corona is permanent in its more fundamental characters. The observed changes in form, in brightness, and in relative extension, are obviously due to secondary modifications of the conditions to which the corona owes its existence.

The circular form which was ascribed to the corona in the older observations can scarcely be regarded—even in the roughest sense of the word—as correct. On the contrary, the apparent form of the corona is always very irregular, in consequence of the greater extension and the greater relative brightness of certain parts. Upon the whole, there is

* "The Observatory," December, 1884, p. 378.

† It may not be unnecessary to state that what the photographer has to seize upon on his plates is the small excess of photographic power of the air-glare increased by the coronal light from behind over that of the air-glare alone. For this purpose the greatest care is necessary to select the most suitable time of exposure, and to arrest the slow development of the plate at the proper moment. Unless the attempt is made at a high elevation, the impression upon the plate must be a very slight one, and the developed image can only be seen under favourable conditions of illumination. Great care must be taken that all instrumental effects have been carefully eliminated. A convenient way of distinguishing effects upon the plate which are due to the instrument, is to take pictures with the instrument alternately on the west and on the east side of the meridian.

‡ The principal points of the discussion of the nature of the corona which follows were suggested in a discourse given at the Royal Institution, February 22, 1885, entitled "On the Solar Corona."

an observed tendency of the brighter parts of the corona to assume a square form in consequence of the greater extension of the coronal matter at the latitudes between the poles and the equator of the sun—that is, over the zones of maximum spot-action. The corona is frequently less extended over the poles and over the equatorial regions of the sun.

A noticeable exception to this state of things occurred in 1878, when the most remarkable features of the corona were two extended equatorial rays which could be traced to a distance of several solar diameters. We shall have to consider, further on, some circumstances which may have had a large influence in bringing about this state of the corona.

In addition to these large changes in the external form of the corona, there is a complex structure within it which appears to be in continual change. This inner structure was observed by Professor S. P. Langley in 1878, under very favourable conditions, with a telescope of 5 inches aperture and a power of 50.

He sums up his observations in the following words :—*

1. Extraordinary sharpness of filamentary structure.
2. Arrangement not radial, or only so in the rudest sense.
3. Generally curved, not straight lines.
4. Curved in different directions.
5. Very bright close to the edge, fading out rapidly, fading out wholly (this part of corona) at 5′ to 10′ from it.

In addition to this more minute structure, there are large bright portions, apparently streaming outwards, and often leaving between them less bright spaces, which have the appearance of rifts. There are also curved forms which seem to turn round and to return to the sun.

We must not forget that the corona has thickness as well as extension, and that the forms seen by us must appear more or less modified by projection. Rays inclined towards or from the observer would be materially altered in respect of their apparent position on the sun, and long rays in the nearer or more distant part of the corona would appear to start from parts of the sun other than those to which they really belong. For the same reason the increase of intrinsic brightness of the corona towards the sun's limb must be much less than the increase of brightness as seen by us, of which no inconsiderable part must be due to the greater extent of the corona in the line of sight as the sun is approached. Besides the real changes in the corona which have been observed at different eclipses, there are several sources of apparent change which may have modified the photographs taken of the corona. Of these may be mentioned—the state of the air at the time; the kind of sensitive surface employed; the length of exposure; whether

* Report T. S. Eclipse, 1878, Washington, p. 209.

the image has been formed by a lens which shortens and enfeebles the ultra-violet part of the light, or by a mirror which furnishes an image more truly representing the corona in the nature of the light existing in it. The difficulties which seemed to lie in the way of a satisfactory explanation of the forms and of the enormous extent of the corona, caused some doubts to be entertained as to the corona being a true solar appendage, and various views were formerly put forward to endeavour to explain the corona as an optical appearance only, arising from our atmosphere, from a lunar atmosphere, or from cosmical dust. Mr. De la Rue, in his address before Section A of the British Association in 1872, says truly, "The great problem of the solar origin of that portion of the corona which extends more than a million of miles beyond the body of the sun, has been, by the photographic observations of Colonel Tennant and Lord Lindsay in 1871, finally set at rest, after having been the subject of a great amount of discussion for many years."*

These earlier views are too completely a part of the history of the subject to need mention here, but for the circumstance that Professor Hastings has recently revived the theory of Delisle, that the corona is an optical appearance due to diffraction.

Professor Hastings bases his theory upon the behaviour of the bright line, 1474, which he saw, in his spectroscope, change in length east and west of the sun during the progress of the eclipse at Caroline Island in 1883. He assumes, in his explanation of this observation, that Fresnel's theory of diffraction may not apply in the case of a solar eclipse, and he suggests that at different moments the phases of the light waves may change so that they no longer form a continuous periodic series, and that it is possible, at such great distances, that the interior of the shadow may not be entirely dark, and that sufficient light may come inside to give to an observer on the earth the appearance of a bright aureole around the moon.†

Professor Hastings considers the simpler explanation of his observation which has been suggested, that the change in length of the line which he observed might be due to a scattering by our air of the light from the brighter part of the corona, and, therefore, might not indicate any change in the corona itself during the progress of the eclipse, to be untenable, on the ground that the air was too clear, and "diffusion absolutely insensible." He supports this strong statement by saying that the photographs taken by the English and by the French observers showed a sensibly black moon, and that "in the photograph of the coronal lines, H and K, taken by the English observers these lines ended abruptly at the moon's edge."‡

* Report B. A. Advanc. Science, 1872, p. 6.

† Report of Expedition to Caroline Island, 1883, Washington, p. 105.

‡ *Idem*, p. 107.

Captain Abney, F.R.S., who has the photographs taken at Caroline Island under examination, informs me that:—

"The diffusion during that eclipse was not insensible, as the lines H and K are distinctly visible across the black moon as dark lines. It is true that H and K, as bright lines, do stop at the moon's limb, but these lines are not coronal lines, as they belong to the prominences. In the Egyptian eclipse—which was a very short one—the prominences were far over the moon's limb, and the diffusion due to the atmosphere was such that the lines H and K were shown as bright lines over the moon. In the Caroline Island eclipse the prominences were much less marked and more hidden during the eclipse than was the case in Egypt, and it appears that the diffusion by the air must have been much greater in the former (Caroline Island) than in the latter, since it is the light from the hidden sun which was evidently reflected and re-reflected. On one side of the moon's limb H and K are seen reversed, whilst on the other they are reversed beyond the bright lines.

"In both cases the reversals are rather faint, but as strong as the reversal which was seen on the corona spectrum at the Egyptian eclipse. In my opinion, in the photographs of the corona with the longest exposure (I am not now speaking of spectrum photographs) the moon is not shown as perfectly black, but I should not like to found any theory very definite as to this, as it might be due to over-development, but I think not."

It should be mentioned that during the time that Professor Hastings observed the change in length of the line 1474, photographs of the corona were taken by M. Janssen, and by Messrs. Lawrance and Woods. M. Janssen says: "Les formes de la couronne ont été absolument fixes pendant toute la durée de la totalité."* The photographs taken by Messrs. Lawrance and Woods show that the corona suffered no such alterations in width and form as would be required by Professor Hastings' theory, during the passage of the moon across the sun.

For other points raised by Professor Hastings, and for his discussion of former spectrum observations of the corona, I must refer to his memoir.†

The evidence in favour of the corona being a true solar appendage appears to me to be of overwhelming weight. It seems difficult on any other hypothesis to explain satisfactorily—(1) the observed and the photographed spectra of different parts of the corona; (2) the visibility of the planets Venus and Mercury as dark bodies when near the sun; (3) the filamentous, and especially the peculiar curved structures seen in photographs of the corona; (4) the close agreement of photographs taken at different times during an eclipse, and

* "Annuaire pour l'An 1884," p. 859.

† *Vide ante.*

especially between photographs taken during the same eclipse at places many hundreds of miles apart.

At the same time a very small part of the light which is seen about the eclipsed sun must be due to diffusion by our atmosphere of the coronal light itself, especially of the very bright part near the sun's limb; and we have an indication of the amount of this diffused light from the apparent illumination of the dark moon, where the effects of diffusion will be most strongly present. During some eclipses the part of the sky where the sun and moon are may be faintly illuminated by light reflected from those regions of the atmosphere near the horizon which are still in direct sunlight.

It may be well to mention the principal hypotheses which have been suggested in explanation of the corona.

1. That the corona consists of a gaseous atmosphere resting upon the sun's surface and carried round with it.

2. That the corona is made up wholly or in part of gaseous and finely divided matter which has been ejected from the sun, or received by it, and which is in motion about the sun from the forces of ejection, of the sun's rotation, and of gravity, and possibly of a repulsion of some kind.

3. That the corona resembles the ring of Saturn, and consists of swarms of meteoric particles revolving with sufficient velocity to prevent their falling into the sun.

4. That the corona is the appearance presented to us by the unceasing falling into the sun of meteoric matter and of the débris of the tails of comets.

5. That the coronal rays and streamers are, at least in part, meteoric streams strongly illuminated by their near approach to the sun, neither revolving about nor falling into the sun, but permanent in position and varying only in richness of meteoric matter, which are parts of eccentric comet orbits. This view has been supported on the ground that there must be such streams crowding richly together in the sun's neighbourhood.

6. The view of the corona suggested by Sir William Siemens in his solar theory.*

The sun must be surrounded by a true gaseous atmosphere of relatively limited extent, but there are several considerations which forbid us to think of a solar atmosphere, in the proper sense of the term, that is of a continuous mass of gas held up by its own elasti-

* Since this lecture was read my attention has been called to the papers by Professor O. Reynolds, "On the Tails of Comets, the Solar Corona, and the Aurora considered as Electric Phenomena," and "On an Electrical Corona resembling the Solar Corona," in vol. v, 3rd Ser., "Lit. and Phil. Soc.," Manchester, pp. 44–56, and pp. 202–209. Professor Reynolds considers the solar corona to be a species of that action known as the electric brush, and to be well represented by discharging electricity from a brass ball in a partially exhausted receiver.

city, which rises to a height sufficient to afford an explanation of the corona which streams several hundred thousand miles above the photosphere.

Gravitation on the sun is about twenty-seven times as great as on the earth, and an atmosphere extending to a moderate coronal height, even if it consisted of a gas thousands of times lighter than hydrogen, would have more than metallic density at the sun's surface, a state of things which spectroscopic and other observations show cannot be the case.

There is another consideration from the rapid increase of density which would take place sunwards in such an atmosphere. Each stratum would be compressed by the weight of all the strata above it, and therefore in descending by equal steps the density of the atmosphere would increase in geometrical ratio. Professor Newcomb gives as an example an atmosphere of hydrogen; such a gas, though heated to as high a temperature as is likely to exist at a height of a hundred thousand miles above the sun, would double its density every five or ten miles.* There is no approach to so regular and so rapid an increase of density to be observed in the corona.

Another circumstance which puts a continuous gaseous atmosphere out of question is the fact that comets have passed unscathed through the coronal regions. Shooting stars passing with the relatively small velocity of thirty or forty miles per second through our atmosphere, rarefied as it is, at the height of fifty or sixty miles, are instantly burnt up. Resistance and heat increase as the square [or more probably for such high velocities as the cube†] of the velocity, yet the nucleus of a comet has passed through several hundred thousand miles of coronal matter with a velocity of 300 miles per second without suffering any sensible loss of velocity. These considerations are amply sufficient to show that the theory of a solar atmosphere of gas of the extent of the corona held up by its own elasticity cannot be entertained.

As we have reason to believe that the corona is an objective reality about the sun, matter of some sort must exist wherever the corona is seen to extend. The questions before us are—(1.) In what form does the matter exist? (2.) Whence does it come? (3.) What are the dynamical conditions under which it can exist at such great heights above the sun?

(1.) On the first of these questions as to the condition of the matter, the spectroscope has given us definite information.

The spectrum of the corona is compound, and consists of three superposed spectra.

(*a*.) A bright continuous spectrum, which informs us that it comes from incandescent solid or liquid matter.

* "Popular Astronomy," p. 259. † See Bashforth, "Phil. Trans," vol. 158, p. 417.

(*b.*) A solar spectrum, which shows that the incandescent solid or liquid matter of the corona reflects to us light from the photosphere.

(*c.*) A spectrum of bright lines, which is relatively faint and varies greatly at different eclipses. We shall consider this spectrum more particularly further on; it is sufficient at this part of the argument that we speak of this spectrum so far only as it tells us of gaseous matter which accompanies the solid or liquid matter.

It is scarcely necessary to say that solid or liquid matter can exist in the corona only in the form of discrete particles of extreme minuteness.

The corona must, therefore, consist of a fog, in which the particles are incandescent, and in which the gaseous matter does not form a continuous atmosphere. Some of the considerations we have already had before us, make it evident that this coronal fog, except very near the sun, must be of a degree of tenuity surpassing any experience we possess from terrestrial experiments. In order to give some definiteness to our conceptions, let us suppose a single minute liquid or solid particle in each cubic mile. A fog even so extremely attenuated, or even much more so, would probably be fully sufficient to give rise to the corona, under the enormous radiation to which it is subjected.

(2.) The next question we have to consider is whether the matter of the corona is of solar origin, or whether it comes upon the sun from without.

Two external sources of the coronal matter have been suggested, and are widely held, namely:—(*a*) meteroids, and (*b*) the lost matter of the tails of comets.

(*a.*) The solar system is crowded with meteoroids revolving in all kinds of erratic orbits, and we know that the earth encounters many thousands of them every hour, but the sun is in a different position with regard to such of these bodies as belong to our system. In order to fall into the sun, the planetary meteoroids would have to be thrown into it, through some disturbance of their orbits, produced by planetary attraction, or by collision with other streams, unless we admit a slow retardation of velocity produced by a resisting medium.

There may be meteoroids which fall directly into the sun from space. Mr. Denning's recent observations seem to show that the solar system encounters meteor streams which may be moving with great velocity through space.*

Many of these bodies may fall into the sun, but we have no knowledge of conditions which would ensure so steady an inflow of meteoroids as would be needed to maintain the observed extent of the corona in a state of permanence about the sun.

(*b.*) The other suggestion which has been made regards the corona

* "Month. Not. R. Ast. S.," vol. xlv, p. 93. See also subsequent papers.

as fed by the lost matter of the tails of comets. We must remember that the matter which comes from the nucleus of a comet, and forms its tail, and is then lost, has been shown by the spectroscope to consist in nearly all comets, of carbon, hydrogen, nitrogen, and possibly oxygen.* If this matter is condensed into the discrete particles which form the tail, in the same conditions of chemical combination as it existed originally in the nucleus, we should expect these particles to be again vaporised in their near approach to the sun; and under these conditions we should expect to find the corona to be mainly gaseous, and to give a spectrum similar to that which is produced by the emitted light of comets. We know that such is not the case; there is, however, a single observation by Tacchini at Caroline Island, in which in one part of the corona he suspected two of the bands which are present in the ordinary cometary spectrum. His words are:— "Dans le spectre du grand panache, qui était faible et presque continu, et que l'on voyait seulement à fente large, j'ai observé deux bandes qui m'ont semblé être analogues à celles que j'ai observées dans les spectres de comètes, c'est-à-dire, la centrale et la moins réfrangible."† The terms in which this unique observation is given show that the lines, even if truly present, were faint and exceptional, and cannot be regarded as characteristic of the coronal light.

It may indeed be suggested that the cometary matter suffers decomposition at the time when it becomes luminous near the nucleus, and that carbon may be separated in a finely divided state, and go to form part of the lost matter of the tail. In the case of comets which have more than one tail, or exhibit rays driven off with a curvature different from that of the principal tail, there is good reason to believe, as Bredichin has endeavoured to show,‡ that each tail or caudal ray consists of matter different in density, which has been separated by a force of repulsion varying as the surface. It would appear doubtful, even on this view, if the supply of comets' tails is sufficiently regular in amount to maintain a permanent corona about the sun.

It seems to me to be much more probable that the corona is fed from the sun itself. This view is supported by the spectroscopic evidence, for the coronal gas is shown to consist of substances which exist also in the photosphere. The structure seen in the corona is much more in harmony with the view that the matter is going up from the sun, than that it is coming down upon the sun.

An examination of the photographs taken at eclipses, or of Mr. Wesley's admirable drawings from them, can scarcely fail to lead an unbiased student to the same conclusion as that which was forced

* "Phil. Trans.," 1868, p. 559, and "Proc. Roy. Soc.," vol. xxxiii, p. 1.

† "Annuaire pour l'An 1884," p. 862.

‡ "Annales de l'Observatoire de Moscou," and "Astron. Nachr.," No. 2411.

upon Mr. Lewis Swift when he observed the corona of 1878:—"I was irresistibly led to the conclusion that the corona, whatever may be its nature, is not a solar atmosphere, nor an inflow of meteoric matter, as many suppose, but rather an outflow of something."* These considerations appear to me to be of great weight in support of the view, that though some meteoroid and some cometary matter may fall into the sun, the corona consists essentially of matter coming from the sun.

(3.) We have now to consider under what dynamical conditions matter coming from the sun can take on forms such as those we see in the corona, and can pass away to such enormous distances, in opposition to gravitation, which is so powerful at the sun.

There is another celestial phenomenon, very unlike the corona at first sight, which may furnish us with a clue to the true answer to this question. The head of a large comet presents us with luminous streamers and rifts and curved rays, which are not very unlike on a small scale some of the appearances which are always present in and are peculiar to the corona. We do not know for certain the conditions under which these cometary phenomena take place, but the only theory upon which they can be satisfactorily explained, and which now seems on the way to become generally accepted, attributes them to electrical disturbances, and especially to a repulsive force acting from the sun, probably electrical, which varies as the surface, and not like gravity, as the mass.† A force of this nature in the case of highly attenuated matter can easily master the force of gravity, and as we see in the tails of comets, blow away this thin kind of matter to enormous distances in the very teeth of gravity.

If such a force of repulsion, acting from the sun, is experienced by comets, it must also be present near the sun, and may well be expected to show its power over the matter ejected from the sun's surface.‡

* Report Total Solar Eclipses of 1878 and 1880, Washington, p. 231.

† "Proc. Roy. Inst.," vol. x, p. 9; also Bredichin, "Annales de l'Observatoire de Moscou," vol. v, No. 2, p. 39; "Astr. Nachr.," No. 2411; and papers by Faye in the "Comptes Rendus." Stokes, "On Light as a Means of Investigation," p. 70 *et seq.* O. Reynolds, "On Cometary Phenomena," "Mem. Lit. and Phil. Soc.," Manchester, vol. v, p. 192.

‡ As a contribution to the history of opinions involving more or less distinctly the idea of repulsion, it may be well to give the following words by Professor Young ("Amer. J. of Science," vol. i, May, 1871, p. 7):—"On the one hand, that of Professor Norton and Mr. Proctor, whose views regarding these rays (the *long* faint rays) are nearly identical, and represent them to be streams of matter, similar to cometary substance or auroral." In a foot-note Professor Young says further:—"Since my name has sometimes been referred to in connexion with the so-called 'Auroral Theory of the Corona,' it is proper for me to state that I make no claim to be its originator. So far as I know, Professor Norton was the first to work out and publish a connected theory of the subject, basing his conclusions largely upon

The existence of a force, which, under suitable conditions, may become one of repulsion at the sun's surface, is not hypothetical only, for we have reasons to believe that such a force must really be present there. Though we have no definite knowledge of the distribution of electricity on the surface of the sun, we do know that chemical and mechanical actions are taking place there which must be accompanied by electrical disturbances. It seems to me that these disturbances, which must be of a high order of magnitude, bring about the magnetic changes on the earth which are observed to take place in connexion with solar phenomena.*

The grandest displays of terrestrial electrical disturbance must be altogether insignificant in comparison with the electrical changes which must accompany the ceaseless and fearful activity of the photosphere. Not to mention the frequent outbursts of heated gas thousands of miles high, and over areas in which the earth could be engulphed, there is the unceasing formation of the fiery photospheric cloud-granules about as large as Great Britain. Surely it is not too much to say that our terrestrial experience of lightning and of

his discussions of Donati's comet, which were printed in this Journal some years ago. Professor Winlock also informs me that he has held and published a very similar opinion, and so I think have more than one of the European astronomers. My own father, more than twenty years ago, was accustomed to teach from the same chair of astronomy which I now occupy, an essentially similar doctrine. Thus the idea had long been familiar to me, and, I presume, more or less so to astronomers generally.."

It may be well to give a more direct reference to the papers of Professor W. A. Norton. He says, speaking of comets ("Proc. Amer. Ass.," 1854, p. 166):—"The tails of comets flowing away under a repulsive force from the sun." . . . . . "[this repulsive force] to consist of the impulsive action of auroral matter flowing from the sun." Again, speaking of the corona, he says: "The aigrettes of auroral matter flowing off chiefly from the polar regions into space." In a subsequent paper ("Proc. Amer. Ass.," 1859, p. 167) Professor Norton defines his idea of the repulsive force as "a general force of cosmical repulsion exerted by all cosmical masses."

Mr. Proctor's views will be found in his work, "The Sun, the Ruler of the Planetary System," 3rd Ed., 1885, pp. 326—427.

For M. Faye's views on a repulsive force, see "Annuaire pour l'An 1883," also "Annuaire pour l'An 1885," and numerous papers in the "Comptes Rendus." Reference should also be made to the conjectures on the existence of a repulsive force thrown out by Sir John Herschel in his Cape Observations.

* Professor Stokes and Professor Balfour Stewart have both speculated on the connexion between solar disturbances and terrestrial magnetism, and have both imagined that the operative solar change is thermic—not electrical, and that it is through radiation that it affects the condition of the earth in such a manner as to be manifested by magnetic disturbances, though the modes in which these philosophers have conjectured that this takes place are wholly different. In a subsequent note I have suggested that the operative solar change is electrical, and that the action is probably one of statical induction.—August 20, 1885.

auroræ fail to supply us with any adequate basis for a true conception of the electric forces in action on the sun.

The phenomena of comets show not merely a highly electrical condition of the sun's surface, but also the permanence of an electric potential of the same kind, whether negative or positive.* Though we do not know enough of what is taking place at the sun to define the conditions which may cause the matter ejected from the sun's surface to have a high electric potential of the same name, yet we can see that broadly all the different actions which take place there, and to which the electric disturbances are probably due, are parts of one continuous process going on always in the same direction, namely, the transference of energy from the interior to the photosphere, and the loss of the energy there, in the radiant form.

We must bear in mind that a strongly electrified state of the solar surface would not act as a force of repulsion upon discrete particles of matter insulated from each other, such as exist in the tails of comets and in the corona, unless these particles possessed an electric potential of the same kind as the solar surface. If these particles were in an unelectrified condition, the action of the sun would be one of statical induction only, altering the original distribution of electricity over their surfaces, but powerless to change in any sensible manner the positions of their centres of gravity in space, because the attraction on one side of each particle would be balanced by the repulsion on the other.

* The sun's potential may be regarded as due to actions of some kind always going on, or to a permanent charge received at some past time. The sun if once charged with electricity of the same name would doubtless remain so charged, as Mr. Crookes' experiments appear to show that a vacuum would be a perfect insulator.

If the sun has been charged with electricity of one name, we do not know how this came about, though more than one probable conjecture might be hazarded. Some facts mentioned further on as to the influence of Mercury and of Venus upon the coronal matter would seem to make it very probable that these planets are permanently charged with electricity of the other name to that of the sun. If this should hold good also of the more distant planets (we know nothing of the absolute potential of the earth's surface), we should have the planets charged with one kind of electricity, and the sun charged with the opposite electricity. As we have reason to believe that the sun and the planets formed originally one cosmical mass, the question may be suggested whether these changes of electricity of opposite names can have been brought about in connexion with the separation of the matter which forms the planets from that which exists in the sun.

If we regard the sun as possessing an electric potential of one name, it is not absolutely necessary to suppose the local electric disturbances which are spoken of in the text. Electric disturbances are undoubtedly taking place there, and through these the ejected matter might come to have a higher potential than it possessed as forming part of the sun. Through these local disturbances some of the matter of the corona might have sometimes a higher or lower potential of the same name, and in this way might arise one of the varying conditions upon which the observed changes in the corona depend.—August 20, 1885.

If we grant the existence of a high electric potential of the sun's surface, we become possessed of a means of explanation of the chief coronal phenomena, provided we accept the conclusion to which our arguments have already led us, that the matter of the corona is of solar origin.

The photosphere is the seat of ceaseless convulsions and outbursts of fiery matter. Storms of heated gas and incandescent hail rush upwards, or in cylones, as many miles in a second as our hurricanes move in an hour. Dante's and Milton's poetic imaginings of Hades fall far below the common-place scenes at the solar surface. Is it then going beyond what might well be, to suppose that some portions of the photospheric matter, having an electric potential of the same kind as that of the solar surface, from which they come, and ejected, as is often the case, with velocities not far removed from that which would be necessary to set them free from the sun's attraction, should come under the action of a powerful electric repulsion, and so be carried upwards, and from the sun?

If we take this view of things, we are able to accept the objective reality of many of the very long coronal rays, which seem to rest upon sufficient testimony. At the eclipse of 1878, Professor Langley traced the coronal matter to a distance of twelve solar diameters, and he adds: "I feel great confidence in saying that (this distance) was but a portion of its extent."* Professor Newcomb traced this ray to about the same distance, "six degrees from the disk."† Such distances are small as compared with the extent of the tails of comets.

This view of the corona is in harmony with the source of the matter, and of the forces which the structure of the corona almost irresistibly suggests, namely, that these have their seat in the sun. We should expect, what we find to be the case, that there is usually great coronal richness and extension over the spot zones where the solar activity is most fervent. Matter blown upwards by an electrical repulsion would rise with the smaller rotational velocity of the photosphere from which it started, and would appear to lag behind in its ascent, and so give rise to the curved rays, which are so common a feature. We may well suppose that the forces of eruption and of subsequent electrical repulsion would vary in different places, and not be always strictly radial; under such circumstances a structure, similar to that which the corona presents, might arise. A force of repulsion would also be present among the similarly electrified particles of the corona, acting in all directions, and would cause these particles to separate from each other, during their ascent from the sun; the amount of this diffusion would depend upon several factors, among others, upon the original velocity of ascent, and upon the density and the degree of electric potential of the repelled stuff.

* Report Total Eclipse, 1878, Washington, p. 208. † *Idem*, p. 104.

A relatively very small amount of matter, under this diffusing force, would suffice to give rise to the corona, and we can see how the extremely attenuated state of the corona, consisting as it must do, of minute particles widely separated, it may be by miles each from the other, may have been rapidly brought about.

It is now time to consider the gaseous matter which we know to be associated with the coronal particles, but not to form a continuous gaseous atmosphere. The gas which exists with the incandescent particles, and which the spectroscope shows to have come from the photosphere, may have been carried up as gas, or have been in part distilled from the condensed matter which forms the coronal particles, under the enormous radiation to which they are exposed. Such a view of the gas which is present in the corona, would not be out of harmony with the circumstance that the amount of gas relatively to the incandescent particles appears to vary (at the last eclipse in Caroline Island it seems to have been but very sparingly present), nor with the very different heights to which different bright lines may be traced at different parts of the corona and at different eclipses. Gases of different vapour-density would be acted upon differently by an electric force of repulsion which varies as the surface, and would to some extent be winnowed from each other; the lighter the gas, the more completely would it come under the sway of repulsion, and so would be carried more rapidly to a greater height than a gas more strongly held down by gravity. The relative proportions, as well as the actual amounts, at different heights in the corona, of the gases which the spectroscope shows to exist there, would vary from time to time; they would depend in fact also on the largeness of supply from below, in other words, upon the state of activity of the photosphere, and in this way there would come about a relation probably between the corona and the prominences.

The varying amount of gas in different parts of the corona is illustrated by the following statement in the Report on the Eclipse of 1882, by Captain Abney and Professor Schuster:—

"The ring in the green (1474) is particularly strong in the south-western quadrant, and hardly visible at some other points of the sun's limb. The yellow ring (D_3) is much fainter on the whole, but more uniform all round the sun."

Further on (p. 270) they say—"As regards the corona, we may perhaps point out that hitherto the position of only one true coronal line had been fixed, though two other lines had been suspected. The corona during the late eclipse seems to have been especially rich in lines. Thollon observed some in the violet without being able to fix their position, and Tacchini could determine the position of four true corona lines in the red; from the photograph we have been able to

measure about thirty additional lines, thus increasing the number of lines considerably."*

Captain Abney informs me as follows : " The spectrum of the corona had fewer lines in the Caroline Island eclipse (1883) than in the Egyptian eclipse (1882), and the corona was much brighter at one limb than at the other in 1883. I think I can trace reversed Fraunhofer lines beyond the bright lines H and K away from the moon's edge."

It would seem probable that at the time of the eclipse of 1883, the amount of light-emitting gas was smaller relatively to the number of incandescent particles than at the time of the eclipse of the previous year. This supposition agrees with the fact that the scattered solar light, showing the Fraunhofer lines, was strong in 1883.

There may be another connexion between the corona and the prominences besides that of a supply of gaseous matter, namely, one due to an increase of electric potential of the ejected matter when the prominences are numerous and large.

The electric disturbances which accompany the formation of large sun-spots are well known to be of sufficient magnitude to be felt upon the earth, by causing changes in the distribution of the terrestrial magnetism sufficiently great to affect our instruments.† The Astro-

* "Phil. Trans.," 1884, pp. 264 and 270.

† We do not know the mode in which the sun acts upon our magnets. The solar action may be a direct one due to changes in the sun's magnetism, or to an electromagnetic action due to electric currents, or to electrified matter in motion with a high velocity. The views suggested in this lecture of the sun's electrified state, and of the nature of the corona may possibly throw some light on this point. Two distinct modes of the sun's action on the magnetic needle seem to be possible :—

(*a.*) The sun being a charged conductor separated from the earth, also a conductor, by an insulating vacuum, would affect the distribution of the earth's electricity by its power of statical induction. As the earth rotates currents would be set up about it to effect the redistribution of electricity required to satisfy the inducing influence of the sun. May we not find in these earth-currents an explanation of some of the phenomena of the earth's magnetism? However this may be, the changes in the sun's statical induction which would follow from the shooting forth of the electrified matter of the corona, may well so affect the earth-currents as through them to bring about the disturbances observed in the needle. The electrified matter of the corona which leaves the sun will still go on, even when too diffused to be visible, and will still continue to produce upon the earth the effect due to its charge of electricity. The amount of this action will depend greatly upon the direction of the projected matter relatively to the position of the earth.

(*b.*) The other possible mode of action of the corona would be to suppose an electromagnetic action upon the earth. The electrified coronal matter moving with a high velocity would act similarly in this respect to electric currents. Among other difficulties we must consider the rapid decrease of electromagnetic action at a distance.

If the sun is a charged body, then in consequence of continually parting with matter charged with electricity of the same name as that of the sun's charge, the sun's potential would be slowly decreasing. This consideration would be in support,

nomer Royal, writing of the magnetic activity of the year 1882, says : "The month of November, which was characterised by the appearance of a very large sun-spot, being particularly disturbed with remarkable magnetic storms on November 17, 19, and 20, and many interesting cases of lesser disturbance."*

We can scarcely doubt but that similar electric disturbances of exceptional magnitude accompany the formation of the prominences ; indeed these phenomena may themselves be, in part at least, electric discharges analogous to terrestrial auroræ.† However this may be, we can scarcely doubt that large electric disturbances accompany them. Tacchini takes the view that electricity plays a chief part in the prominences, and believes that he is able to show a connexion between these phenomena and corresponding changes in the magnetism of our globe.‡

Hitherto in our discussion of the forces which may be active in the corona, we have taken account only of the influence of electrical changes which take place upon the sun. Now these changes at the sun make themselves felt upon the earth ; we may then well suppose, with a high degree of probability, that the earth,§ and especially the

of the conjecture thrown out in the last sentences of the text, that the corona was formerly of larger extent, and that it will continue to diminish.—August 20, 1885.

[My attention has been called this day to a paper by Prof. O. Reynolds, "On the Electro-dynamic Effect which the Induction of Statical Electricity causes in a Moving Body. This Induction on the part of the Sun a probable Cause of Terrestrial Magnetism." "Mem. Lit. and Phil. Soc.," Manchester, vol. v, 3rd Ser., p. 209.—Sept. 29, 1885.]

* Report of the Astronomer Royal, 1883, p. 13.

† See Balfour Stewart, "Proc. Roy. Inst.," vol. iv, p. 60.

‡ "Reale Accademia dei Lincei (March 1, 1885), S.N., vol. i, p. 181. Tacchini says :—"Ciò viene anche a corroborare l'opinione mia e di qualche altro, che cioè nel fenomeno delle protuberance solari l'elettricità attia una parte rilevante, da dovere forse considerare non poche di esse come fenomeni puramente ellettrici, come aurore polari, capaci di indurre sul nostro globo i correspondenti disturbi magnetici ; . . . . noi possiano intanto considerare come cosa assicurata alla scienza, che il fenomeno della maiehie solari, quelle delle protuberanze ed il magnetismo terrestro variano così dì accordo."

At the same sitting Professor Respighi took a different view (p. 174) and stated he did not consider the prominences to be of a nature to occur in periods, and that he could not admit a connexion between the maxima and minima of the prominences and the elements of terrestrial magnetism. At the following sitting, March 15 (p. 228) Tacchini replies to the objections of Respighi, and endeavours to show that Respighi has been influenced by his preconceived views of the nature of spots and prominences.

§ Mr. Broun, in his discussion of the variations of the earth's magnetism ("Proc. Roy. Soc.," vol. xxiv, p. 231), says :—"It is shown that those changes (in 1844 and 1845) occur at intervals of twenty-six days, or multiples of twenty-six days. . . As this period is that of the sun's rotation relatively to the earth, it appears to follow that the earth has some action on the sun, or (more probably) on some ray-like emanation from the sun, which causes these changes in the earth's magnetism."

nearer planets Venus and Mercury, exert an influence on the electrified and attenuated matter of the corona.

The elaborate researches of Mr. De la Rue and Professor Balfour Stewart appear to show an influence exerted by Venus and Mercury upon the solar regions of spot action.

We know nothing of the electric distribution on Venus and on Mercury, but it seems more than probable that these bodies, as well as the meteor-swarms nearer to the sun, have an influence in determining the mode of outflow of the electrified coronal matter in the directions in which they happen to be. The influence may be one of attraction, giving rise to coronal extension or rays from the corona, or to repulsion, in which case we might have what appears to us as a rift directed towards the body.

We have not sufficient data to furnish certain information on this point, but it may be of interest to quote the following sentences from Mr. Trouvelot's Report of the Eclipse of 1878* :—

" There is a fact connected with this eclipse, which, if not due to a singular coincidence, would seem to point to some attractive action of the planets on the solar atmosphere (corona). On the day of the eclipse Mercury and Venus were in almost opposite points of their orbits, with the sun between and almost on a line with them, while the Earth on the same day was in a part of its orbit which formed the apex of an equilateral triangle having for base the line joining Mercury and Venus. Knowing this, it is perhaps singular, and anyhow very remarkable, to see that the eastern wing of the corona was directed on a straight line to Mercury, while the western appendage was directed on a straight line to Venus. The coincidence was still greater. As in regard to the sun, the two planets were not exactly on the same line, Mercury being a little to the north, while Venus was a little to the south of the ecliptic; the solar appendages have shown the same peculiarity, their axes being a little inclined to each other."

I may say that the inclination of the axes of coronal extensions on the two sides of the sun may be seen in the photographs of this eclipse. It should be stated that Professor Newcomb, who observed the coronal extension towards Venus, says :—"I tried to judge whether the western one (ray) pointed towards the planet Venus, then plainly visible near the horizon. The direction was apparently very slightly below that of the planet." Professor Newcomb's words seem to show that he did not make any allowance for refraction, which would make the planet when near the horizon appear sensibly higher than its true place.

If sufficient evidence should be forthcoming in the future to establish a sensible influence of the planets upon the corona, we should not

* Page 93.

expect to see the coronal matter in all cases moving exactly towards or from a planet, because this matter would be also under the influence of a motion in the direction of its primary repulsion, and also of one of rotation about the sun.*

There has been some difference of opinion as to whether the corona is uniform in constitution from the sun's limb outwards, or whether it consists of two parts, which have been distinguished by the names, "inner corona" and "outer corona."

There can be no doubt that at certain times, and in certain solar latitudes, a lower part of the corona, such as that described by Professor Langley, extending from about 5′ to 10′, is so much brighter than the parts outside of it that it seems to form what may be called an inner corona. At the same time, the photographs of different eclipses, and Mr. Wesley's drawings from some of them, show distinctly that all the stronger indications of structure can be traced down almost to the sun's limb, and that the brighter parts within some 6′ to 10′ of the limb, are not equally bright all round the sun. This brighter inner part is represented very strongly in several drawings which accompany Mr. Stone's paper on the eclipse of 1874, especially in one by Mr. Wright.† There seems great probability that the corona

* General Tennant, F.R.S., informs me that since this lecture was read, he has calculated the places of Mercury, Venus, and Mars for the eclipse of 1871 and the eclipse of 1882. He says:—

"The positions at the eclipse of 1871 are—

Mercury	position angle	100° 39′
Venus	,, ...	278° 40′
Mars	,, ...	80° 40′

Mercury is thus not far from the direction of the great prominences lettered H and I (see catalogue at page 27 of my report, 'Mem. R. Ast. Soc.,' vol. xlii), and corresponds to the greatest extension of the coronal matter, namely, 45′ in my table. Venus is near the group lettered V, W, and X, of which group V is less only to H and I in height, and corresponds to the next greatest extension of the corona namely, 34′ 56″ in my table. The real heights of the visible extensions, allowing for the foreshortening, would be for Mercury, 41′ 3″ or 45′ 31″, according to the reading taken; and for Venus, 47′ 05″. Any such calculation, however, implies a form of the coronal extension which does not exist. The more foreshortened ray would, in fact, on account of its breadth, seem longer in proportion than the one which is seen more nearly perpendicularly to its axial direction; and in this case this consideration would tend to reduce the real extension of the Venus ray. Mars does not seem to have any marked ray directed to him, but any such ray would be much foreshortened if it existed.

"At the time of the eclipse of May 16, 1882 ('Phil. Trans.,' vol. clxxv, Plate 13), we should have the effects of the planets Mercury and Venus coincident, and not much foreshortened, in the coronal pictures. The combined effects of these planets are shown in the protruding angle at the upper left side of the engraved corona. There seems a marked protrusion of the general light thereabouts which would be opposite to the planets."—August 15, 1885.

† "Mem. Roy. Astron. Soc.," vol. xlii, pp. 43, 51, and 53.

is of the same nature throughout, but that there is often so much more matter, in other words, the coronal fog is so much denser, within 5′ to 10′ of the limb, that under the effects of projection, and when seen by the eye or with a very low power, this part of the corona appears to be marked off from the corona beyond. It is possible that a clue to the real state of things may be found in the photographs of the corona of 1878. When these are examined the long equatorial rays seen by eye, can be traced a little distance beyond the bright corona, but it is found that the corona, as a whole, is not drawn out at this part, so as to extend to several solar diameters, but that these great extensions consist of rays or streamers coming out from the general coronal mass, something in the way in which fainter rays often extend from the principal tail of a comet. They may be due to a similar cause, namely, the electric repulsion acting upon particles which are more completely under its sway, either from their less specific gravity, or their more highly electrified condition. The consideration presents itself, whether in this state of things, we have only an extreme case of the conditions always present in the corona, which gives rise to the appearances which have suggested the distinction of an "inner corona" and an "outer corona."

There is another question which awaits consideration, namely, whether the corona rotates with the sun. It seems obvious that if the corona is due to a supply of matter and to forces coming from the sun, then the coronal structure and the degree of extension, which are produced by them, at any part of the sun, would continue to be produced by these agencies at that part of the sun, and in that sense the corona would rotate. In the case of the more distant and diffused parts, the rotation could scarcely be of one and the same material object, any more than in the sweep of a comet's tail at perihelion, the corona being constantly renewed and reformed over each part of the solar surface. If we suppose the corona to come under the influence of an external force as that of a planet, then we should expect the ray drawn out towards it, or the rift formed opposite to it, to continue to be directed to this external object, and to be independent of the solar rotation. The subpermanence of any great coronal form, therefore, would probably have to be explained by the maintenance for some time of the conditions upon which the form depends, and not by an unaltered identity of the coronal matter; as in the case of a cloud over a mountain top, or of a flame over the mouth of a volcano.

We have to consider another question: What becomes of the coronal particles? Are they carried away from the sun, as the matter of the tails of comets is lost to them; or do they return to the sun?

The results of eye observations, as well as of the taking of photographs with different exposures, have shown that there is great probability that the corona has not an outer boundary, but that it is lost

in an increasing faintness and diffusion. The absence of a limit is probably true only of the faint outer parts of the corona. Within, and especially about the distance from the sun's limb to which the so-called "inner corona" usually extends, there is evidence of an apparent arrest of coronal matter, due in part probably to the effects of perspective, and within this distance are seen numerous rays which turn round and descend towards the sun. These returning curved forms are well shown in Mr. Wesley's drawings of the eclipse of 1871.*

We are led to the conclusion that many of the coronal particles return to the sun, but that in the case of other particles which form the stronger coronal rays and streamers, there is no return, but that they leave the sun, and, at the same time, separate more widely from each other by their mutual repulsion, and become too diffused to be visible. The state of extreme attenuation of this diffused coronal matter—such that the nuclei of comets pass through it without sensible retardation, enables us to see that the corona may be maintained at an extremely small expenditure of solar material. Among other considerations it may be mentioned that an electric repulsion can maintain its sway only so long as the repelled particles remain in the same electrical state; if through electric discharges the particles cease to maintain the electric potential they possess, there will be no longer any force of repulsion acting upon them, and gravity will be no longer mastered. If when this takes place, the particle is not moving away with a velocity sufficiently great to carry it from the sun, the particle will return to the sun. Of course, if the effect of any electric discharges or other local conditions has been to change the potential of the particle from positive to negative, or the reverse, as the case may be, then the repulsion would be changed into an attraction acting in the same direction as gravity.

This ceaseless outflow of extremely minute particles, very widely separated from each other, may possibly throw some light on another phenomenon which has not yet been satisfactorily explained, namely, the zodiacal light.

The views which I have ventured to put forward in this lecture would lead us to expect that a more extended and more brilliant corona surrounded the sun in early geological time, and that if the skies were then of their present degree of clearness, the corona would probably have been visible about the sun.

May the corona have been still faintly visible in the earliest ages of the human race? Are there any philological traces of it in the earliest words and ideas connected with the sun?

On those eastern plains, where the air is of so great purity, did early men still see faintly a true παρήλιος?

Similar considerations point to a slow secular diminution in extension

* "Mem. Roy. Astron. Soc.," vol. xli, Plates 6, 7, 8, and 10.

and in brightness of the corona, as the sun slowly loses heat, and the actions of the photosphere become less fervent.

The candle of the sun is burning down, and so far as we can see, must at last reach the socket. Then will begin a total eclipse which will have no end:

"Dies illa
Solvet seclum in favilla."

"Results of the Harmonic Analysis of Tidal Observations." By A. W. Baird, Major R.E., and G. H. Darwin, F.R.S., Fellow of Trinity College and Plumian Professor in the University of Cambridge. Received March 19, 1885.

The harmonic analysis of continuous tidal records, inaugurated by a Committee of the British Association in 1868, has now been carried out at a considerable number of ports. Some of the earlier results were collected together in the Reports to the Association in 1872 and 1876, and in a paper by Sir W. Thomson and Captain Evans, read before the Association in 1878, but the largest mass of data is contained in the tide tables now being annually published for the Indian ports under the authority of Her Majesty's Secretary of State for India.

The Report of the last Committee of the British Association, published in the volume for the meeting at Southport in 1883, is entirely theoretical, and has been adopted in India as a manual of the method of harmonic analysis. It is there shown how the results of the analysis are to be presented in a form appropriate either for theoretical treatment or for mechanical prediction by the instrument of the Indian Government in London. It is also shown how the scattered results, referred to above, may be reduced to the form which has been adopted as a standard. Major Baird has collected the whole of the Indian results, and those contained in the Reports of 1872 and 1876, and, by the aid of his staff of computers at Poona, has reduced them to this standard form. The greater part of the annexed tables is the result of this work.

We must refer to the Report to the British Association for 1883 for an explanation of the method of harmonic analysis, but it will be well to give a few words of explanation.

Each one of the tides, into which the oscillation of sea-level is regarded as analysed, is expressed in the form—

$$\mathrm{fH}\cos(V+u-\kappa).$$

$V+u-\kappa$ is the argument of the tide, and increases uniformly with the time, so that this term represents a simple harmonic oscillation of the sea-level with semi-range f H.